Design and Evaluation of Displays for the Crew Exploration Vehicle

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Crew members aboard NASA's Orion Crew Exploration Vehicle (CEV) are envisioned to monitor and command the vehicle primarily through graphical computer displays and electronic procedures. Not only will this make for a lighter vehicle, but this paperless "glass cockpit" concept can make crew tasks more efficient by collocating vehicle information and controls. If this paperless glass cockpit is properly designed, crew members can obtain insight into vehicle states, use electronic procedures to complete tasks effectively, and respond to off-nominal situations quickly. If it is not properly designed, however, the displays could lead to design-induced human errors, such as sending incorrect commands, high crew workload, poor situational awareness, and extensive need for training. Thus, display standards and an iterative design and evaluation process have been employed as ways to optimize display design.

Background on Displays and Electronic Procedures

The CEV commander and flight engineer will be able to monitor system states across subsystems, send vehicle commands, interact with electronic procedures, and, if needed, manually fly the vehicle from three display units. More than 50 displays have been designed for use throughout all phases of flight, including during prelaunch and post-landing activities.

Crew members have the ability to perform all display tasks manually or with electronic procedures. During manual operation, crew members can navigate to a display and use a cursor control device, cursor knob, or edge keys to traverse through and select commandable elements. Commands are sent through pop-ups. The electronic procedure system, referred to as eProc, is designed as a powerful alternative to reduce crew workload. eProc assists crew members by highlighting vehicle states on a display and cueing up appropriate displays, pop-ups, and commands. eProc is also linked to fault messages, such that crew members can quickly access procedures to any message that appears on the fault summary or log displays. Thus, eProc is a critical component of crew interaction with other displays and with the caution-and-warning system. The focus of the display development work is to ensure that crew members have accurate and easy interactions with the display, both manually and with eProc (see figure 1).

Iterative Display Design Process

A human-centered, iterative design process is used to increase efficiency, effectiveness, and satisfaction of crew members interacting with displays. The process—which is led by a small interdisciplinary team composed of members of the Mission Operations Directorate, Human Engineering, and the Crew Office, which includes the Rapid Prototyping Lab (RPL)—begins by taking early concepts developed by flight and system experts in PowerPoint and reworking them based on the needs of the task to be performed, compliance with Human System Integration Requirements (CxP 70024, Rev D.) and Orion Program Display Format Standards (CxP 72242, Rev. A). Display standards, which are used to define all common display elements (e.g., symbology, text, modes of interaction, and colors), ensure consistency in look and feel across displays and allow crew members to use their experience and knowledge about interaction with one display to facilitate their interaction with other displays. Display standards have also reduced prototype development and software coding time by creating modular and reusable display components. This translates to cost savings for both the vehicle and flight software.

Once the team is satisfied with the PowerPoint concept, RPL programmers develop an interactive prototype that can be evaluated by crew members in a human-in-the-loop evaluation. In preparation for the evaluation, the team works with the subject matter experts of each system to develop a series of representative nominal and off-nominal scenarios and procedures that allows participants to get a feel for how interaction with the display will occur.

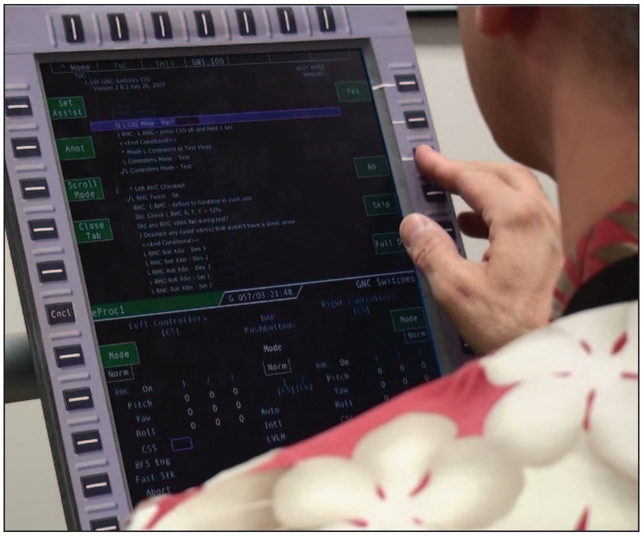

Fig. 1. Human-in-the-loop evaluation participant interacts with eProc and system display.

Tasks are selected that exercise frequent, critical, and unique display interactions. State files are created to model vehicle telemetry within the prototypes; these are based on commands that are sent or failures built into the scenarios. Flight displays are driven by a combination of the Advanced NASA Technology Architecture for Exploration Studies [ANTARES] simulation software and state files.

Interactive prototypes and procedures are reviewed frequently by the team and updated based on emerging issues. The team has found that design elements that seemed like good ideas in PowerPoint sometimes become glaring issues when they are viewed on the display hardware and interacted with. Additionally, the translation of paper procedures into eProc has revealed that writing electronic procedures is not as simple as placing a paper procedure into an electronic format. Electronic procedures need to be written in a unique way so that they work seamlessly with corresponding displays, are integrated within the eProc architecture, and are understandable by the user. Thus, frequent review and iteration of display designs and procedures prior to crew evaluations has proved to be an essential part of the process.

Once the team is satisfied with prototypes and procedures, Human Engineering leads the human-in-the loop evaluations of the displays with crew members and representatives. Each evaluation includes five to nine participants with a range of experience from the space shuttle, International Space Station, and Russian Soyuz capsule. They include both "experts," those individuals who are familiar with the displays, and "novices," those individuals who are seeing these displays for the first time.

Participants are provided with an overview of the displays and modes of interaction during the evaluation. They are then asked a set of questions to gauge their initial impressions of the displays as well as to prime them for thinking about layout, terminology, and other aspects of the displays. Next, these participants go through a series of procedures and simulated mission control callouts that allows them to interact with display components. During this interaction, all participant comments and any observations about behavior (e.g., errors and observed frustration or points of confusion) are captured. Interview questions and questionnaires provide additional information about whether participants are interpreting display elements correctly and are satisfied with the design of the displays. After the evaluation, the results are analyzed, and issues and recommendations for design changes are presented and reviewed by the team and system experts.

By capturing crew member inputs through this iterative design process, design issues are identified before any flight software is written. Display and cockpit operability improvements are of minimal cost at this stage of design. So far, 31 display formats have gone through at least one of the 14 total human-in-the-loop evaluations that have taken place. Through these early prototype evaluations, more than 100 usability issues, including potential critical errors, have been identified and resolved via redesign. As an example, in the propulsion display evaluation it was revealed that the indication of auxiliary (+X) jets firing after a main engine failure was not visually salient enough—*none* of the participants noticed the jets firing.

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continued

Fig. 2. *During an evaluation, Human Engineering records crewmembers' comments and observations. Automated data analysis software runs in the background to capture design-induced errors. The results of the evaluation are used to improve the design of the displays.*

Based on this finding, the jet icons were altered to fill in with a bright white when firing and were changed to an unfilled gray outline when unavailable. As an additional benefit, the evaluations have identified design simplifications to make crew members' tasks easier and reduce flight software costs (see figure 2).

Summary

The structured nature of the design and evaluation process has allowed CEV displays to go from paper prototypes to interactive prototypes that are evaluated and improved on in a matter of a few weeks—a very cost-effective method with significant benefits. Continuing and future work will include more integrated, phase-based evaluations, continued refinement of display designs, validation of display standards, and integration of the display suites with the vehicle flight software. Although the displays designed and evaluated thus far are specific to Orion, they could be generically applied to any vehicle. Other spacecraft will have electrical power systems, life support systems, propulsion systems, etc. Features of the design of Orion displays, the design process, lessons learned, eProc standards, and display standards could be applied to any future space vehicle that has a paperless, glass cockpit design.